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CHARLES V. WALKER, F.R.S., F.R.A.S., PRESIDENT, in the Chair.

Barber, Samuel, *The Lyceum, Liverpool*;
Tyrer, Richard, *Grove House, Mansfield, Notts.*;
were balloted for and duly elected Fellows of the Society.

XXXIX. *On Deep-Sea Thermometers.*

By Captain J. E. DAVIS, R.N., F.R.G.S.

THE objects of this paper and of the experiments and observations recorded therein, are :—

1. The ascertainment of the effect of pressure on thermometers used for deep-sea purposes.
2. To obtain a scale whereby observations made by the thermometers now in use could be corrected for pressure.
3. To obtain a scale whereby observations made previously by other thermometers can be utilized.

In the early part of the year 1868 the attention of the Hydrographer of the Navy was directed to the unsatisfactory nature of the deep-sea Six's thermometers then in use, and it was pointed out to him that, so far as those who had had experience could judge, we had retrograded in the construction rather than advanced; but as one of early make (such as were used by Sir James Ross in 1840) could not be procured, no actual comparison could be made.

The self-registering thermometer known as "Six's," invented by Mr. James Six, of Canterbury, was described by him in the 'Philosophical Transactions' of the Royal Society in 1782; but as the description, as recorded in those 'Transactions,' is by no means clear in regard to the principle on which the thermometer is constructed, but dwells rather on its mode of self-registering (which was the *point* of the invention), it may not be out of place here, when recording observations and experiments made with this truly valuable instrument, to append a brief description of it.

As originally made, it consisted of a long cylindrical bulb united to a smaller tube of more than twice its length, bent up and down in the form of a siphon with the cylinder in the centre, and terminating in a small oval bulb at the top,—the lower portion of the siphon being filled with mercury, the long bulb, the other parts of the tube, and about a third of the small bulb with rectified alcohol, the remaining part of the small bulb being filled with highly compressed air, which acts as a spring to compress the mercury and cause it to rise in the opposite tube, on the contraction (from cold) of the spirit.

A steel bar enclosed in glass, with flattened projecting glass ends, is enclosed in each limb of the siphon above the mercury, the flattened end preventing the mercury from passing them: these, from their weight, would rest on the mercury; but each has a fine hair tied to its upper extremity and bent against the interior of the tube, to act as a spring with sufficient elasticity to keep the bar or index supported in the spirit, while the application of a horse-shoe magnet close to the glass, will draw them down to the surface of the mercury in each stem.

Without altering the principle, a modification in the form has since been made; thus, instead of the long cylindrical bulb in the centre a bulb filled with spirit is joined to the upper end of the siphon, abreast of, but rather lower than, the opposite bulb. By this arrangement the instrument is made more compact, and its strength increased by lessening the number of bends, thus better adapting it to the comparative rough usage it has to be subjected to when used for deep-sea purposes.

On a rise of temperature, the spirit in the bulb will expand and depress the mercury in one stem, while it raises it in the other, carrying with it the index, whilst a return of cold will contract the spirit in the bulb, allowing the elastic force of the compressed air to depress the mercury in the opposite stem and raise it in the other, each index retaining its position at the extreme of heat and cold attained, while the top of the mercury in each limb denotes the temperature of the time being. It will be observed that the cold is indicated at the upper end of the one stem, and heat at the upper end of the other, and the scales or graduations thus become reversed.

The objections made to these thermometers were:—

1. Their fragility, the slighest jar or blow often breaking them.
2. The necessity of their being always kept in a vertical position.
3. The uncertainty of the register, the indices being generally capable of being shaken down.
4. Their large size, in connexion with friction in passing through the water.
5. The substance they were mounted on, being generally wood, became so swollen by pressure of the water as often to render them incapable of being withdrawn from the case.

It was also considered that in all thermometric observations at great depths we had been "working in the dark," in that we had no idea of the effect pressure had on the instrument, and consequently on the recorded results; and it was reasonable to suppose that as the action of a thermometer was affected *in vacuo*, an opposite effect would be had by placing them under pressure, the more especially as in the one case the pressure of only one atmosphere, or 15 lbs. to the square inch, was removed, while in the other the atmospheres would have to be reckoned by hundreds and the pressure by tons. On this point we were not without actual observation; for Mr. Glaisher, during the year 1844, in some experiments made on the temperature of the Thames near Greenwich with delicately constructed instruments, found that the indications of temperature were affected by pressure on the bulb of the thermometers, and that at a depth of only 25 feet, or about three fourths of an atmosphere, the readings were increased by 2°; but no definite conclusion could be arrived at from these observations in respect to our deep-sea thermometers, beyond the fact that they were liable to be so affected.

It was therefore suggested to the Hydrographer—

1. That the author might be placed in personal commumication with different makers in respect to the best construction for the purpose required, and
2. That a series of experiments should be made by placing some

thermometers in an hydraulic press in conjuction with one in an hermetically sealed iron bottle (as a standard) and subjecting them to pressure, that they should be kept under pressure sufficient time to allow the thermometer within the bottle to take up the temperature without, and then the whole compared with the standard.

The first suggestion was immediately acceded to; and those makers from whom the Meteorological Department obtained instruments (viz. Messrs. Elliot, 449 Strand, Mr. Casella, Hatton Garden, and Messrs. Negretti and Zambra, Hatton Garden) were applied to, and the following desiderata submitted to each.

Desiderata for Deep-sea Mercurial Thermometers.

1. That they could not be injured by being placed in a horizontal position or even in a reversed position and shaken[*].
2. That the bulbs should be entirely protected[†].
3. That the ends of the indicators should be made so exact to the diameter of the tube that there could be no possibility of globules of mercury getting above the end.
4. That the indicators should be made so stiff with the frictional hairs that no vibration, shaking, or tapping, could possibly move them.
5. That the plate on which the scale is marked should be made only sufficiently wide for the scale, and also that it should be made so that the tubes could be sunk in it to one-half their diameter, thus bringing the indicator on a level with the scale and avoiding error by parallax in reading off.
6. That between the brasses (which fix the tube to the plate) and the tube a piece of wash-leather should be inserted, to prevent breakage by a jar[‡].
7. The range of temperature necessary for ocean observations (and all that need be made visible on the scale) is from +20° to 100°.
8. Small size.
9. Lowness of price[§].

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[*] Much stress was laid on this point, as it is almost impossible to keep them always in a vertical position on shipboard.

[†] This protection was intended merely to enable the instrument to be handled with more safety than it could be without.

[‡] As many thermometers had been broken at these points, it was concluded that this trifling omission had been the cause.

[§] This was explained as not being intended to beat the maker down, or to get an inferior instrument, but to enable more to be used for observing with.

10. The use of wood in mounting to be discontinued. The Hydrographer suggested ebonite for mounting thermometers on; this was adopted and found to answer.

Subsequently Mr. Pastorelli, 208 Piccadilly, expressed a wish to make some for trial; this was complied with; but as Messrs. Negretti and Zambra did not respond to the request, the number of makers was still confined to three; and six thermometers were ordered from each. These instruments were sent in (hereafter called the Hydrographic-Office pattern), and Mr. Balfour Stewart, of the Observatory at Kew, was consulted as to the *modus operandi* of testing by pressure; and he approved of that already suggested.

A difficulty arose in respect to a hydraulic press: the use of some in London could not be obtained; and others were not adapted to the purpose; so that the testing was deferred, and some of the instruments were sent to H.M.S. 'Gannet,' then deep-sea sounding on the edge of the Gulf-Stream, and afterwards some to H.M.S. 'Lightning' for her dredging cruise.

On the return of these vessels, the conflicting nature of the temperatures obtained from those supposed to exist (as derived from observations in other localities) rendered the necessity of ascertaining the nature and amount of error due to pressure the more imperative.

At this juncture Mr. Casella (being much interested, although believing that pressure would neither affect the thermometers nor their results) undertook to have a testing-apparatus constructed at his own expense, capable of producing a pressure of three tons to the square inch. This hydraulic testing-apparatus was made by Messrs. Kittoe and Brotherhood, Engineers and Millwrights, Clerkenwell.

At a meeting of the Committee of the Royal Society, held in the Hydrographer's Room in April 1869, and at which all the appliances relating to deep-sea sounding were placed before them, the plan of operation for testing the thermometers was discussed, and that by means of an iron bottle approved. Dr. Miller, V.P.R.S., proposed encasing the full bulb in an outer covering of glass containing air, in order to permit the lighter fluid (air) to be compressed without affecting the bulb within: and one such was directed to be made; but instead of the outer casing being filled with air, it was nearly filled with alcohol, which being heated to reduce the quantity of air, the bulb was then hermetically sealed. Mr. Casella was also directed to make others that would facilitate the observations.

At the time these experiments were proposed, it was not known that a thermometer had been constructed at the suggestion of Mr. Glaisher, by the late Admiral FitzRoy's directions, with the view of removing the difficulty of pressure; this was done by encasing the long bulb at the back of the instrument in glass, and nearly filling the space between the case and the bulb with mercury*; and one on this principle was then in the Instrument-room of the Meteorological Office; but although some had been used for deep-sea purposes, the further issue of them had been stopped on account of their fragility, and thus the means for obtaining accurate observations were virtually the same as before.

During the delay caused by the want of an hydraulic press, a Committee of the Royal Society was appointed to direct the investigation of the ocean observations since so successfully carried out in H.M. Ships 'Lightning' and 'Porcupine,' and the proposal by Dr. Miller to encase the full bulb, recorded above, was made without the knowledge of such a one having been previously made; but as it differed in form, it has been called the "Miller pattern" to distinguish it.

It was decided to test them at pressures equal to the following depths in the ocean, viz. 250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2250, and 2500 fathoms, the rule to be applied being 33 feet = one atmosphere = 15 lbs. on the square inch. From this the following Table was constructed for use:—

	Pressure.		
Fathoms.	Atmospheres.	lbs.	tons.
250	45·5	682	0·30
500	90·9	1363	0·61
750	136·4	2045	0·91
1000	181·8	2726	1·21
1250	227·3	3408	1·51
1500	272·7	4089	1·82
1750	318·2	4771	2·12
2000	363·6	5452	2·43
2250	409·1	6134	2·74
2500	454·5	6817	3·05

On the 3rd of May the hydraulic testing-apparatus, or press, was placed in the back yard of Mr. Casella's house, against a wall which screened it from the sun, and it was tested to two tons pressure.

The next day the following thermometers were taken to Hatton Garden, viz.:—

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* See Meteorological Report, No. 1, 1857.

Nos. 56 and 57	Casella...	Hydrographic Office pattern.
66 and 67	Elliott ...	„ „ „
72 and 73	Pastorelli	„ „ „
No. 1.........	Casella...	Specially made with an extra-thick cylinder bulb to *defy* compression.
3.........	„ ...	Spherical bulb; extra-thick glass. This thermometer was made, at the special request of one of Mr. Casella's workmen, in order to resist effect by pressure.
4.........	„ ...	Short cylinder bulb; extra-thick glass.
6.........	„ ...	A glass cup fitting over bulb, designed by Mr. Siemens.

All the above were Six's thermometers with the bulbs unprotected.

No. 2.........	Casella...	Glass-encased bulb, as proposed by Dr. Miller, but with the case nearly filled with spirit.
5.........	„ ...	Long cylinder bulb at the back, encased in glass, and nearly filled with spirit.

These instruments were first compared in air and then immersed in a tub of water, No. 57 being placed in an iron bottle. Set the indices and placed the thermometers in the cylinder of the press, and pumped on a pressure equal to 250 fathoms, and kept it on two hours, when Dr. Miller and Dr. Carpenter arrived and the pressure was removed.

It is useless to record the result of this first experiment; or it may rather be stated that the results were *nil*, except ascertaining the weak points of the process adopted; these were:—

1. The iron bottle was useless, the water having forced its way through the worms of the screw and the leather washer at the top, into the cylinder.

2. We had used too many thermometers, as difficulty was found in reading off and re-setting the indices quick enough to prevent alteration taking place before re-immersion in the cylinder.

It was therefore necessary, either that the iron bottle should be made to withstand the pressure, or some standard found to compare with, independent of it. The bottle was afterwards made tight, and burst under a pressure of about 5000 lbs. to the square inch; but as the Miller-pattern thermometer subsequently proved so near perfection, it was decided to use that as a standard for the Hydrographic-Office pattern *.

It was also necessary to reduce the number of thermometers, and also of the readings, to a minimum.

With the view of testing the efficiency of Dr. Miller's pattern (No. 2) it was placed in the cylinder with No. 57, and subjected to a pressure of 4032 lbs. (about 1480 fathoms) for a quarter of an hour, with the following result.

EXPERIMENT No. 1 (pressure =1480 fathoms). Dr. Miller reading.

Thermometer.	Minimum.		Maximum.		Diff. of Max.	Remarks.
	Before.	After.	Before.	After.		
2	47°·5	47°·5	47°·5	48°·0	0°·5	Thermometer in tube 47°·5.
57	47·5	47·5	47·5	55·0	7·5	

This experiment at once proved the efficacy of the encased bulb; and the experiment was repeated with more thermometers, with the same pressure and for the same period of time.

EXP. No. 2 (pressure =1480 fathoms). Dr. Miller reading.

Thermometer.	Minimum.		Maximum.		Diff. of Max.	Remarks.
	Before.	After.	Before.	After.		
Encased 2	47°·5	47°·5	47°·5	48°·5	1°·0	
„ 5	48·0	47·5	47·4	48·3	0·9	
1	47·5	47·5	47·5	53·5	6·0	
3	48·5	48·0	47·5	56·0	8·5	
6	48·0	47·5	47·5	58·0	10·5	
57	48·0	47·5	47·5	55·0	7·5	
Phillip's alpine.	...	...	47·7	118·0	70·3	

It will be seen by this experiment that while the mean difference of the encased bulbs was only 0°·95, that of the two made to defy compression was 7°·25, that with the cover 10°·5, and the Hydrographic-Office pattern the same as in No. 1, 7°·5.

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* I was not aware at that time of the existence of the enclosed Phillip's thermometer as designed by Sir William Thomson.

The "Phillip's" was an ordinary make, with a very small bulb; and the great difference shown by it proved that the amount of compression is in proportion to the thickness of the glass; but in immediate connexion with the subject the experiment clearly demonstrated two facts, viz.:—

1. That very nearly all the difference, or error, is due to pressure on the full bulb; and

2. That by encasing the bulb we have nearly a perfect instrument. This result was the more important in rendering future experiments, in a manner, independent of the iron bottle, which again failed with a new washer.

Notwithstanding the satisfactory result obtained in enabling us to decide on a thermometer for future use, it was necessary, if possible, to establish a scale whereby temperatures already taken with instruments of the Hydrographic-Office pattern might be corrected for pressure, and also to ascertain if all, or what part, of the difference shown under pressure in the Miller pattern was due to calorific effect produced by sudden compression of the water in the cylinder or by compression of the unprotected parts: preparation was accordingly made to continue the experiments.

It being necessary, as before stated, to reduce the number of the thermometers, and also the readings, to a minimum, the following were selected, viz.:—

Nos. 2 and 5	Casella...	Encased bulbs.
56 and 57	„ ...	Hydrographic-Office pattern.
73.........	Pastorelli	„ „ „
67.........	Elliott ...	„ „ „
9641.........	Casella...	Alpine.

These were attached to a float (to avoid immersing the hand in the water) and placed in the cylinder filled with water, to remain all night; the cistern, from which the water is pumped into the cylinder, was filled, and also a tub of water for replenishing placed by the side in order that the water in each might be, as nearly as possible, of the same temperature in the morning.

As the relative readings of the maximum and minimum of each thermometer were compared in both air and water and found to agree, and as a progressive increase in the temperature of the cylinder was observed, the difference between the minimum and maximum indices is used: the maximum mercury is always recorded; but as it had not always time to adjust itself to its normal state, it can only be used as a check to the minimum readings.

The thermometers were read in the order in which they are placed; when all were read, the indices were set as quickly as possible, and the instruments at once lowered into the cylinder and the pressure applied.

May 5th the first series of experiments were made, Mr. Casella reading.

First Series of Experiments.

No. 1 (pressure =250 fathoms =682 lbs.). Under pressure forty minutes.

Thermometer.	Max. Mercury.	Min. Index.	Max. Index.	Diff.	Remarks.
	°	°	°	°	°
2............	46·5	46·1	47·6	1·5	Water in tub .... 45·8
5............	46·8	46·3	47·6	1·3	„ tube .... 48·5
56............	46·5	46·1	47·2	1·1	
57............	47·2	46·2	47·2	1·0	As Phillip's was not attached to
73............	47·3	46·0	47·9	1·9	a float, it could not be taken
67............	48·2	46·1	50·0	3·9	out without the insertion of the
Phillip's Alpine	......	47·0	......	......	hand and the displacement of a quantity of water.

No. 2 (pressure =500 fathoms =1363 lbs.). Under pressure twenty-five minutes.

2............	47·7	47·5	49·6	2·1 ?	Water in tub .... 46·4
5............	47·8	47·8	49·4	1·6	„ tube .... 49·0
56............	47·2	47·2	49·9	2·7	
57............	47·8	47·4	50·1	2·7	
73............	47·8	47·5	50·1	2·6	
67............	48·2	47·6	55·5	7·9	

No. 3 (pressure =750 fathoms =2045 lbs.). Under pressure thirty-three minutes.

2............	49·0	48·5	49·5	1·0	Water in tub .... 47·2
5............	48·5	48·6	48·8	0·2	„ tube .... 50·0
56............	48·4	47·8	51·6	3·8	
57............	48·6	48·0	51·8	3·8	No. 67 was taken out safely; but
73............	48·6	48·2	52·4	4·2	while reading off, the full bulb
67............	Broken.				cracked right across.

No. 4 (pressure =1000 fathoms =2726 lbs.). Under pressure thirty-seven minutes.

2............	50·0	49·6	50·8	1·2	Water in tub .... 47·8
5............	49·6	49·5	50·1	0·6	„ tube .... 50·8
56............	49·6	49·5	53·8	4·3	
57............	49·8	49·5	54·4	4·9	
73............	49·5	49·2	55·2	6·0	

Placed another of Elliot's (No. 66) in the cylinder.

No. 5 (pressure =1250 fathoms =3408 lbs.). Under pressure thirty-six minutes.

Thermometer.	Max. Mercury.	Min. Index.	Max. Index.	Diff.	Remarks.
	°	°	°	°	°
2............	50·8	50·4	51·6	1·2	Water in tub .... 48·6
5............	50·4	50·4	50·8	0·4	" tube .... 51·2
56............	50·1	50·1	55·6	5·5	" cylinder ...... 50·5
57............	50·3	50·2	55·8	5·6	" air............... 49·2
73............	50·3	50·2	57·0	6·8	
66............	50·4	49·7	63·0	13·3	

No. 6 (pressure =1500 fathoms =4089 lbs). Under pressure fifty minutes.

2............	51·3	50·8	52·4	1·6	Water in tub .... 49·3
5............	50·3	51·0	51·8	0·8	" tube .... 52·1
56............	50·4	50·5	57·5	7·0	
57............	50·5	50·6	58·0	7·4	
73............	50·6	50·8	59·0	8·2	
66............	50·9	50·5	66·9	16·4	

No. 7 (pressure =1750 fathoms =4771 lbs.). Under pressure thirty minutes.

2............	51·7	51·4	52·8	1·4	Water in tub .... 49·6
5............	51·0	51·5	52·3	0·8	" tube .... 52·1
56............	51·0	51·0	59·0	8·0	" cylinder ...... 51·2
57............	51·0	51·0	59·2	8·2	
73............	50·6	51·0	60·7	9·7	
66............	51·0	50·8	69·5	18·7	

Placed one of Thomson's insulated thermometers in the press.

No. 8 (pressure =2000 fathoms =5452 lbs.). Under pressure thirty minutes.

2............	52·0	51·9	53·5	1·6	Water in tub .... 49·6
5............	51·1	51·6	53·2	1·6	" tube .... 52·4
56............	51·0	51·1	60·6	9·5	" cylinder ...... 51·7
57............	51·1	51·3	61·0	9·7	
73............	51·2	51·4	61·6	10·2	
66............	Broke at a pressure equal to 1848 fathoms.				
Phillip's 9641...	......	......	118·0	71·0	
Thompson*	......	51·0	52·1	1·1	

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* This insulated thermometer is a Phillip's encased in a glass cylinder containing a little spirit, designed by Sir William Thomson.

As the pressure was being pumped on in the last experiment, heard a sharp crack when the gauge indicated a pressure of 2¼ tons: the sound was so loud that it was heard in the house. On taking the instruments out, No. 66 was found to be completely smashed, and must have broken in several places at the same moment.

May 6th.—The following experiment was made with the Hydrographic-Office pattern (not used yesterday) for comparison. Mr. Casella reading.

Pressure =2000 fathoms =5452 lbs. Under pressure seventeen minutes.

Thermometer.	Max. Mercury.	Min. Index.	Max. Index.	Diff.	Remarks.
	°	°	°	°	°
2	53·6	53·5	54·9	1·4	Water in tub .... 51·9
5	53·5	53·6	54·8	1·2	„ tube .... 55·4
53	53·2	53·1	63·0	9·9	„ cylinder ...... 53·5
58	53·7	52·6	63·3	10·7	
71	53·5	53·0	64·3	11·3	
74	53·5	53·2	63·5	10·3	
75	54·9	53·2	62·8	9·6	
Thompson	......	55·2	56·2	1·0	

The results of the first series of experiments are presented graphically in the annexed diagram (Plate V.).

Second Series of Experiments.

June 21st.—The thermometers were placed in the cylinder, which was filled with water; the supply-tub or cistern for pumping in from, and a tub of water standing near the press, were also filled and thus left all night.

June 22nd.—A dull morning, with no sun, all the conditions most favourable for observing.

Before commencing, obtained two tubs of water with 12° difference of temperature (determined with a delicate thermometer), and, to ascertain the time required by one of the Miller pattern to take up temperature, removed one suddenly from one tub to the other (from the cold to the warmer) and then back.

To take up 12° of heat it took seven minutes; the first 6° (as might be expected) were taken up more rapidly than the second.

To lose the same amount of heat, by being placed in the colder water, it took only four and a half minutes.

It was therefore concluded that by allowing the thermometers to remain under pressure eight minutes, the same results would be obtained as if allowed to remain half an hour or more, as in the first series of experiments.

The thermometers used were :—

Standard......	Casella.........	Dr. Miller's pattern.
No. 54.........	„	Hydrographic-Office pattern.
56.........	„	„ „ „
76.........	Pastorelli ...	„ „ „
73.........	„ ...	„ „ „
Thompson ...	Casella.........	Encased (Sir William Thomson's design).

All under pressure 8 minutes.

No. 1. Pressure =250 fathoms =682 lbs.

Thermo-meter.	Max. Mercury.	Min. Index.	Max. Index.	Diff.	Remarks.
	°	°	°	°	°
Standard ...	53·6	53·3	54·0	0·7	Temperature of air......... 55·8
54............	53·8	53·3	54·7	1·4	Water in tub .... 54·4
56............	53·8	53·2	55·0	1·8	„ cistern............ 53·0
76............	54·2	53·8	55·0	1·2	„ tube................ 54·4
73............	53·8	53·5	54·9	1·4	„ cylinder .... 54·4
Thomson...	54·4	......	54·4	0·0	

No. 2. Pressure =500 fathoms =1363 lbs.

Standard ...	54·3	53·8	54·5	0·7	Temperature of air......... 56·7
54............	54·2	53·6	56·7	3·1	Water in tub .... 54·5
56............	54·0	53·7	56·5	2·8	„ cistern............ 54·0
76............	54·5	54·3	56·8	2·5	„ tube................ 54·6
73............	54·0	53·8	56·8	3·0	„ cylinder .... 54·9
Thomson...	53·9	......	54·0	0·1	

No. 3. Pressure =750 fathoms =2045 lbs.

Standard ...	54·6	53·8	55·0	1·2	Temperature of air......... 57·2
54............	54·2	53·9	57·8	3·9	Water in tub .... 54·6
56............	54·2	53·8	57·8	4·0	„ tube................ 54·6
76............	54·9	54·3	58·5	4·2	„ cistern............ 54·7
73............	54·2	53·9	58·5	4·6	„ cylinder .... 54·9
Thomson...	54·6	......	54·6	0·0	

No. 4. Pressure =1000 fathoms =2726 lbs.

Thermometer.	Max. Mercury.	Min. Index.	Max. Index.	Diff.	Remarks.	
	°	°	°	°		°
Standard ...	54·9	54·1	55·6	1·5	Temperature of air.........	58·7
54............	54·6	54·0	59·2	5·2	Water in tub	54·9
56............	54·2	53·8	59·1	5·3	„ cistern............	55·1
76............	55·0	54·6	59·5	4·9	„ tube...............	55·0
73............	54·7	54·1	59·0	4·9	„ cylinder	54·9
Thomson ...	54·3	......	54·6	0·3		

No. 5. Pressure =1250 fathoms =3408 lbs.

Standard ...	55·2	54·2	55·8	1·6	Temperature of air.........	60·0
54............	54·9	53·9	60·3	6·4	Water in tub	55·0
56............	54·9	54·0	60·3	6·3	„ cistern............	55·6
76............	55·5	54·7	61·0	6·3	„ tube	55·3
73............	55·0	54·3	61·7	7·4	„ cylinder	55·6
Thomson ...	54·8	......	54·9	0·1		

No. 6. Pressure =1500 fathoms =4089 lbs.

Standard ...	55·5	54·8	56·3	1·5	Temperature of air.........	61·0
54............	55·0	54·2	62·0	7·8	Water in tub	55·1
56............	55·3	54·3	62·1	7·8	„ cistern..	55·8
76............	55·9	55·0	62·5	7·2	„ tube...............	55·8
73............	55·4	54·7	62·5	7·8	„ cylinder	55·8
Thomson ...	54·8	......	55·3	0·5		

No. 7. Pressure =1750 fathoms =4771 lbs.

Standard ...	55·9	55·2	56·9	1·7	Temperature of air.........	62·0
54............	55·2	55·0	63·3	8·3	„ tub	55·0
56............	55·5	54·8	63·6	8·8	„ cistern............	56·3
76............	56·1	55·7	64·1	8·4	„ tube...............	56·1
73............	55·8	55·0	65·2	10·2	„ cylinder	55·9
Thomson ...	55·1	......	55·4	0·3		

No. 8. Pressure =2000 fathoms =5452 lbs.

Standard ...	56·2	55·5	57·5	2·0	Temperature of air.........	62·4
54............	55·7	55·5	65·2	9·7	Water in tub	55·6
56............	55·9	55·2	65·1	9·9	„ cistern............	57·0
76............	56·8	55·9	65·5	9·6	„ tube...............	56·5
73............	56·4	55·4	66·9	11·5	„ cylinder	56·3
Thomson ...	55·6	......	56·2	0·6		

No. 9. Pressure =2250 fathoms =6134 lbs.

Thermometer.	Max. Mercury.	Min. Index.	Max. Index.	Diff.	Remarks.
	°	°	°	°	°
Standard...	56·5	55·9	57·9	2·0	Temperature of air......... 63·4
54............	56·3	55·4	66·5	11·1	Water in tub .... 56·0
56............	56·3	55·5	66·4	10·9	„ cistern............ 57·8
76............	57·2	56·3	67·2	10·9	„ tube...... .... 57·0
73............	56·8	56·0	68·3	12·3	„ cylinder .... 57·0
Thomson...	55·9	......	56·7	0·8	

No. 10. Pressure =2500 fathoms = 6817 lbs.

Standard...	57·1	56·5	58·7	2·2	Temperature of air......... 63·6
54............	56·7	55·4	68·3	12·9	Water in tub .... 56·0
56............	56·4	55·9	67·9	12·0	„ cistern............ 58·0
76............	57·4	56·9	68·6	11·7	„ tube............... 57·5
73............	56·9	56·3	70·0	13·7	„ cylinder .... 57·0
Thomson...	56·7	......	57·1	0·4	

Note.—While conducting these experiments we caught a small water-worm in the water-tub, placed it in a tube and tied a piece of rag over it, and placed it in the cylinder, subjecting it to a pressure of 3408 lbs. for 8 minutes; it came out alive. Repeated the experiment with a pressure of 4089 lbs. for the same time; after a little time it showed signs of life. Again repeating the experiment with a greater pressure, the bottle was broken and the worm lost by the accident.

The results of the second series of experiments are laid down in the diagram annexed (Plate V.).

TABLE showing the progressive difference for each 250 fathoms by each Thermometer.

By First Series of Observations.

Pressure equal to Fathoms.					Casella.				Pastorelli.	
	2.		5.		56.		57.		73.	
	First diff.	Second diff.	First diff.	Second diff.	First diff.	Second diff.	First diff.	Second diff.	First diff.	Second diff.
	°	°	°	°	°	°	°	°	°	°
0	......		......		......		......		......	
250	1·5	+1·5	1·3	+1·3	1·1	+1·1	1·0	+1·0	1·9	+1·9
500	1·1	−0·4	1·6	+0·3	2·7	+1·6	2·7	+1·6	2·6	+0·7
750	1·0	−0·1	0·2	−1·4	3·8	+1·1	3·8	+1·1	4·2	+1·6
1000	1·2	+0·2	0·6	+0·4	4·3	+0·5	4·9	+1·1	6·0	+1·8
1250	1·2	0·0	0·4	−0·2	5·5	+1·2	5·6	+0·7	6·8	+0·8
1500	1·6	+0·4	0·8	+0·4	7·0	+1·5	7·4	+1·8	8·2	+1·4
1750	1·4	−0·2	0·8	0·0	8·0	+1·0	8·2	+0·8	9·7	+1·5
2000	1·6	+0·2	1·6	+0·8	9·5	+1·5	9·7	+1·5	10·2	+0·5
Mean diff. per 250 fathoms }	......	+0·20	......	+0·20	......	+1·19	......	+1·20	......	+1·27

By Second Series of Observations.

Pressure equal to Fathoms.	Standard.		Casella.				Pastorelli.				Thomson.	
			54.		56.		76.		73.			
	First diff.	Second diff.	First diff.	Second diff.	First diff.	Second diff.	First diff.	Second diff.	First diff.	Second diff.	First diff.	Second diff.
	°	°	°	°	°	°	°	°	°	°	°	°
0......	......		......		......		......		......		......	
250......	0·7	+0·7	1·4	+1·4	1·8	+1·8	1·2	+1·2	1·4	+1·4	0·0	0·0
500......	0·7	0·0	3·1	+1·7	2·8	+1·0	2·5	+1·3	3·0	+1·6	0·1	+0·1
750......	1·2	+0·5	3·9	+0·8	4·0	+1·2	4·2	+1·7	4·6	+1·6	0·0	−0·1
1000......	1·5	+0·3	5·2	+1·3	5·3	+1·3	4·9	+0·7	4·9	+0·3	0·3	+0·3
1250......	1·6	+0·1	6·4	+1·2	6·3	+1·0	6·3	+1·4	7·4	+2·5	0·1	−0·2
1500......	1·5	−0·1	7·8	+1·4	7·8	+1·5	7·2	+0·9	7·8	+0·4	0·5	+0·4
1750......	1·7	+0·2	8·3	+0·5	8·8	+1·0	8·4	+1·2	10·2	+2·4	0·3	−0·2
2000......	2·0	+0·3	9·7	+1·4	9·9	+1·1	9·6	+1·2	11·5	+1·3	0·6	+0·3
2250......	2·0	0·0	11·1	+1·4	10·9	+1·0	10·9	+1·3	12·3	+0·8	0·8	+0·2
2500......	2·2	+0·2	12·9	+1·8	12·0	+1·1	11·7	+0·8	13·7	+1·4	0·4	−0·4
Mean diff. per 250 fms. }	...	+0·22	......	+1·29	......	+1·20	......	+1·17	......	+1·37	......	+0·05

Experiments for Calorific Effect.

The Phillip's encased maximum thermometers (Thompson's) being entirely protected from any effect by compression, it was decided to ascertain by their means the calorific effect produced by the sudden compression of the water in the cylinder; but, as will be seen by glancing through the two series of experiments recorded, there was such a gradual increase in the temperature of the air and also in the water used for supplying the cylinder, that for any delicate observation the conditions were not favourable; the observations for calorific effect were therefore delayed until the weather got colder, when a more equable temperature could be ensured throughout the experiment.

In order to ascertain what time it would require for these instruments to take up temperature (as it was of importance they should not be kept under pressure longer than necessary) the following observations were made, viz.:—

Compared two Thomson's thermometers (Nos. 9640 and 9647) in the air with a delicate thermometer (No. 2528); all agreed.

Placed the three thermometers nearly in a horizontal position in a deep dish containing water (temperature 65°·4); when all agreed, set the indices, replaced them in the water, the bulbs of the three being near together, poured in a little warm water at the furthest side from the bulbs, agitated the water with a pencil, and watched, with a magnifier, the effect. The mercury of the encased thermometers commenced rising almost as soon, and as quickly, as the plain, taking from 1 to 3 minutes to attain from two to three degrees, to the exact temperature of the water: this experiment was repeated several times and with the same results.

Poured in a quantity of warm water with the following results.

			m	s
From	71°·5 to 75°·0 = 3°·5	it took	0	15
„	75·0 to 80·0 = 5·0	„	0	45
„	80·0 to 81·3 = 1·3	„	1	0
„	81·3 to 81·7 = 0·4	„	3	0
Total time of rising 10°·2 ………			5	0

This was an outside period of time, or until a retrograde movement of the mercury was observed as the water cooled: it was therefore considered that 5 minutes would be sufficient time for the Thomson thermometers to take up the most minute portion of heat observable.

For the purpose of observing this heat engendered by pressure, a Six's unprotected thermometer was made by direction of one of the Committee of the Royal Society, having the partially filled bulb open at the top, with a lip to which was firmly secured by wire a small piece of india-rubber tubing closed at the end, with the view of equalizing the pressure on both columns of mercury, and thus recording the amount of heat due to calorific effect only. A small portion of the mercury on the maximum side was oxidized; but it did not affect the reading, as it attained the same level on the scale of temperature as the minimum.

November 12th.—The following observations were made, day cloudy, all the conditions favourable, Mr. Casella reading:—

No. 1. Pressure =2500 fathoms =6817 lbs. Under pressure ten minutes.

Thermometer.	Before.	After.	Diff.	Remarks.	
	°	°	°		°
11424.........	37·8	37·9	+0·1	Temperature in air	40·0
9649.........	37·6	38·0	+0·4	" tub......	41·6
9645.........	37·7	37·9	+0·2	" cistern .	38·8
Committee...	38·0	Broken.		" cylinder	38·0

Heard a crack at 1200 lbs. pressure; on taking the instruments out, found the Committee thermometer broken: the bulb to which the india-rubber tubing was attached was broken off below the bulb; and the tube of the thermometer on the minimum side was broken in one place, and the minimum indicator forced up to the bulb.

Experiment No. 2 (same pressure). Under pressure twenty minutes.

Thermometer.	Before.	After.	Diff.	Remarks.	
	°	°	°		°
11424.........	38·8	38·8	0·0	Temperature in air	43·6
9649.........	38·8	38·8	0·0	" tub......	41·2
9645.........	38·6	38·4	−0·2	" cistern .	41·2
				" cylinder	38·9

It will be observed that the water pumped into the cylinder was a little warmer than that in the cylinder; but as the valve through which it passed into the cylinder is near the top, while the bulbs of the thermometers were at the bottom, the small difference it could have made in the upper water could not have affected them.

By Mr. Casella (previously observed).

Thermometer.	Pressure.	Before.	After.	Diff.	Remarks.
	fms.	°	°	°	
	500	53·5	53·7	+0·2	
	1000	54·0	54·0	0·0	
	1500	54·5	54·5	0·0	
	2000	54·9	55·1	+0·2	

From Meteorological Office.

	2000	60·5	61·1	+0·6	
	2000	61·0	61·3	+0·3	

TABLE showing the result of the foregoing Experiments.

N.B. The figures in antique type are rejected in forming the mean.

Difference.	Pressure.	Per 250 fms.	Difference.	Pressure.	Per 250 fms.
°	fms.	°	°	fms.	°
+0·0	250	0·000	0·4	2500	0·040
0·1	500	0·050	0·2	2500	0·020
0·0	750	0·000	0·0	2500	0·000
0·3	1000	**0·075**	0·0	2500	0·000
0·1	1250	0·020	−0·2	2500	0·000
0·5	1500	**0·083**	+0·2	500	**0·100**
0·3	1750	0·043	0·0	1000	0·000
0·6	2000	**0·075**	0·0	1500	0·000
0·8	2250	**0·089**	0·2	2000	0·025
0·4	2500	0·040	0·6	2000	**0·075**
0·1	2500	0·010	0·3	2000	0·037

Mean 0·0178, calorific effect for each 250 fathoms' pressure.
„ 0·18 „ „ 2500 „ „

It would seem almost unnecessary, for the purpose for which this paper is prepared, to record the above observations at all, so small is the result; but as the amount of heat caused by compression is supposed by some to be much greater, it has been thought best to give the figures in full, with deductions therefrom.

Experiments to determine the amount of Heat produced by friction.

To ascertain if any error *could* arise from heat created by friction in a thermometer passing rapidly through the water, one of Casella's Hydrographic-Office pattern was towed astern of one of the fast river-steamers ('Naiad'), keeping the thermometer well submerged by means of a lead weight attached to the line before it; and with repeated trials at full speed not the slightest difference could be detected.

TABLE showing the Error of the Miller-pattern thermometer.

N.B. The figures in antique type are rejected in forming the mean.

Difference.	Pressure.	Per 250 fms.	Difference.	Pressure.	Per 250 fms.
°	fms.	°	°	fms.	°
0·5	1480	0·083	1·5	1500	**0·250**
1·0	1480	0·167	1·7	1750	0·243
0·8	1480	0·133	2·0	2000	**0·250**
1·5	250	**1·500**	2·0	2250	0·182
1·3	250	**1·300**	2·2	2500	0·220
1·1	500	**0·550**	1·4	2000	0·175
1·6	500	**0·800**	1·2	2000	0·150
1·0	750	**0·333**	1·5	2050	0·182
0·2	750	0·066	1·4	2050	0·170
1·2	1000	**0·300**	1·7	2050	0·207
0·6	1000	0·150	1·1	2050	0·134
1·2	1250	0·240	1·3	2050	0·158
0·4	1250	0·080	1·2	2050	0·146
1·6	1500	**0·270**	1·2	2050	0·146
0·8	1500	0·133	1·2	2050	0·146
1·4	1750	0·200	1·0	2050	0·125
0·8	1750	0·113	1·2	2050	0·146
1·6	2000	0·200	0·8	2050	0·097
1·6	2000	0·200	1·2	2050	0·146
0·7	250	**0·700**	1·9	2500	0·190
0·7	500	**0·350**	1·9	2500	0·190
1·2	750	**0·400**	2·0	2500	0·200
1·5	1000	**0·375**	1·7	2500	0·170
1·6	1250	**0·320**			

Error per 250 fathoms as shown by hydraulic press	° 0·161 mean
Deduct for calorific effect...............................	·018
True error per 250 fathoms	0·143
True error for 2500 fathoms.............................	1·43

Mean Errors of Hydrographic-Office pattern Thermometers, by testing-apparatus, corrected for Calorific effect.

Casella's Thermometers.

Fathoms...	250.	500.	750.	1000.	1250.	1500.	1750.	2000.	2250.	2500.
	°	°	°	°	°	°	°	°	°	°
	1·1	2·7	3·8	4·3	5·5	7·0	8·2	9·5	11·1	12·9
	1·0	2·7	3·8	4·9	5·6	7·4	8·2	9·7	10·9	12·0
	1·4	3·1	3·9	5·2	6·4	7·8	8·3	9·7		
	1·8	2·8	4·0	5·3	6·3	7·8	8·8	9·9		
						7·5	......	9·9		
								10·7		
Mean	1·325	2·825	3·875	4·925	5·950	7·500	8·325	9·782	11·000	12·450
Calorific effect...	18	36	54	72	90	108	126	144	162	180
Error	1·307	2·789	3·821	4·853	5·860	7·392	8·199	9·638	10·838	12·270

Pastorelli's Thermometers.

Fathoms...	250.	500.	750.	1000.	1250.	1500.	1750.	2000.	2250.	2500.
	°	°	°	°	°	°	°	°	°	°
	1·9	2·6	4·2	6·0	6·8	8·2	9·7	10·2	10·9	11·7
	1·2	2·5	4·2	4·9	6·3	7·2	8·4	9·6	12·3	13·7
	1·4	3·0	4·6	4·9	7·4	7·8	10·2	11·5		
								10·3		
								10·3		
								9·6		
Mean	1·500	2·700	4·333	5·267	6·833	7·733	9·433	10·250	11·600	12·700
Calorific effect...	18	36	54	72	90	108	126	144	162	180
Error	1·482	2·664	4·279	5·195	6·743	7·625	9·307	10·106	11·438	12·520

Progressive rate of Error of Hydrographic-Office pattern Thermometers, as shown by foregoing Table, by Testing-apparatus.

Casella.				Pastorelli.			
Depth.	Error.	First diff.	Second diff.	Depth.	Error.	First diff.	Second diff.
fms.	°	°	°	fms.	°	°	°
0 ...	0·000			0 ...	0·000		
250 ...	1·307	1·307	+0·175	250 ...	1·482	1·482	−0·300
500 ...	2·789	1·482	−0·450	500 ...	2·664	1·182	+0·433
750 ...	3·821	1·032	0·000	750 ...	4·279	1·615	−0·699
1000 ...	4·853	1·032	−0·025	1000 ...	5·195	0·916	+0·632
1250 ...	5·860	1·007	+0·525	1250 ...	6·743	1·548	−0·666
1500 ...	7·392	1·532	−0·725	1500 ...	7·625	0·882	+0·800
1750 ...	8·199	0·807	+0·632	1750 ...	9·307	1·682	−0·883
2000 ...	9·638	1·439	−0·239	2000 ...	10·106	0·799	+0·533
2250 ...	10·838	1·200	+0·232	2250 ...	11·438	1·332	−0·250
2500 ...	12·270	1·432		2500 ...	12·520	1·082	
			+1·574				+2·398
			−1·449				−2·798
Difference			+0·125	Difference			−0·400
Equal to an *increase* of effect at the rate of 0°·014 per 250 fathoms' pressure.				Equal to a *decrease* of effect at the rate of 0°·044 per 250 fathoms' pressure.			

It will be seen by the above Tables, that while one set of thermometers show an *increase* of effect under pressure, the other set denote a *decrease*, and the mean of the two would be so small a decrease as not to be appreciable; and the practical conclusion is, that, by the testing-apparatus, the elasticity of the glass is in exact proportion to the pressure applied.

Instructions to Staff-Commander Calver, R.N., for the Experiments to be made afloat.

"May 14, 1869.

"Dear Calver,—The Hydrographer having desired me to give you all the information in my power with respect to the deep-sea thermometers, it will, perhaps, be best (as you wished) for me to put my ideas in writing; at the same time I wish you to understand that I have no authority to do so, and any thing I advise must, of course, be qualified to meet the instructions given you by the Hydrographer.

"As you are aware, I have been engaged lately in making some experiments with deep-sea thermometers under pressure, by means of an hydraulic press; and although we have, I believe, overcome the difficulty of error arising from pressure for the future, still it is of great importance to obtain a scale of error, in order to utilize observations that have been made with instruments hitherto used, which are of similar construction as those experimented with.

"By the experiments made, a scale could be formed for the above purpose; but considering that the means used to obtain that scale may be said to be made under theoretical conditions rather than practical, it necessarily needs the practical observation to verify its correctness before it can be applied, and for which purpose some of each kind will be sent on board.

"Dr. Miller's glass-encased bulb-thermometers must be accepted as standards, as from all experiments made with the press they are affected to so small a degree as not to be appreciable.

"The thermometers sent to you (with the exception of those of Dr. Miller's design, not yet sent in) are—

No. 55	Casella.........	Has not been under pressure.
53	„	Has been under pressure equal to 2000 fathoms.
58	„	„ „ „ „
71	Pastorelli ...	„ „ „ „
74	„ ...	„ „ „ „
75	„ ...	Has not been under pressure.
68	Elliot	„ „ „ „
69	„	„ „ „ „
40	Pastorelli ...	Used in H.M.S. 'Gannet.'
39	„ ...	„ „ „
41	Casella.........	„ „ „
42	„	„ „ „
43	„	„ „ „
38	Pastorelli ...	Used in H.M.S. 'Lightning.'

"It will be necessary not only to test the thermometers that have been under hydraulic pressure, but those also that have been used in the 'Gannet' and 'Lightning;' and I do not think a fine day would be lost if entirely devoted to these observations; and as I believe you would find a depth of 2000 fathoms about sixty miles west from the western extreme of the Porcupine bank, perhaps if the weather promises fine when you are there, the opportunity would be a good one.

"Having ascertained the depth with a detacher, I would advise bending on just above a 56 lb. lead, and one above the other,

Standard Thermometers.
No. 53 or 58
71 or 74
39 or 40
41, 42 or 43
68 or 69—

in all, six thermometers. While obtaining the depth, place all the thermometers to be used in a bucket of surface-water placed *in the shade* and renewed occasionally from the sea.

"When the thermometers are all bent on, open the doors of the cases, set the indices quickly, read and note maximum and minimum (the standard last), and get them over the side and into the water as quickly as possible, and let them down to 250 fathoms; and allowing them to remain five minutes, heave in (very carefully as they come near the surface), read the standard first: generally the maximum index will be on the mercury, read that first, then the top of the mercury on the minimum side, and then the lowest part of the minimum index (attending to Rule 3).

"Repeat the observation, with the same instruments, at 500, 750, 1000, 1250, 1500, 1750, and 2000 fathoms, increasing the weight of sinkers as expedient.

"*Form.*

Thermometer No.	Maker.	Max. Index.	Min. Mercury.	Min. Index.	Remarks, &c.
					Surface temperature by No. .

"Although the thermometers are of such a superior construction that a shake or jar, or being placed in a horizontal or reversed position, is not liable to injure them, still, as these are better avoided, the subjoined rules respecting them may not be out of place.

" *Rules.*

"1. Keep them in a vertical position, either in the box or hanging up; if the latter, take care that in swinging they do not strike against the bulkhead.

"2. Avoid sudden shaking or jars.

"3. *If possible*, let one person always read the results, to avoid personal parallax, and, in reading, hold the instrument nearly horizontal across the face, read as near tenths of a degree as possible; and it is advisable to let a second person look at the readings, merely to check the *degree* recorded. Also let the selected reader practise.

"4. In setting the indices with the magnet, draw them down slowly, as by doing it too quickly it is liable to send a globule of mercury above the index.

"5. When the thermometers are done with for the day, rinse them in fresh water, withdraw them from their cases, wipe them gently, replace them, and place them in the box; wipe the cases well.

"6. In holding the thermometers when bending on, do not hold the case in the hand more than possible, as the heat of the hand is quickly communicated.

(Signed) "J. E. DAVIS."

The experiments at sea were made in strict conformity with the preceding instructions; and the results of these experiments are contained in the following Tables:—

Ocean-Observations by Staff-Commander E. K. Calver, 1869.

Casella's Hydrographic-Office pattern.

N.B. The figures in antique type are rejected in forming the mean.

250 fathoms.		
Thermometer.	Min. Index.	Diff. from Miller.
100–103 (Miller)	48°·0	
53*	49·0	1·0
55	49·2	1·2
58	49·4	1·4
101–103 (Miller)	48·35	
41	49·4	1·05
42	49·6	1·25
43	49·5	1·15
100–103 (Miller)	48·5	
41	49·2	0·7
42	49·5	1·0
43	50·4	1·9
53	49·5	1·0
55	49·4	0·9
58	50·8	**2·3**
374 fathoms.		
100–103 (Miller)	45·95	
55	48·4	1·64 †
58	47·8	1·23 †
Mean		1·186
Correction for Miller		0·143
Error at 250 fms.		1·329

500 fathoms.		
Thermometer.	Min. Index.	Diff. from Miller.
374 fathoms.		
100–103 (Miller)	45·95	
55	48·4	3·27 ‡
58	47·8	2·47 ‡
500 fathoms.		
100–103 (Miller)	46·75	
53	49·0	2·25
55	48·8	2·05
58	49·0	2·25
101–103 (Miller)	47·5	
41	50·0	2·5
42	49·5	2·0
43	51·5	**4·0**
100–103 (Miller)	46·75	
41	48·8	2·05
42	49·3	2·55
43	49·6	2·85
53	49·3	2·55
55	49·0	2·25
58	50·5	3·75
Mean		2·530
Correction for Miller		0·286
Error at 500 fms.		2·816

* An error of 1° is applied to No. 53 throughout.

† Reduced to 250 fathoms.

‡ Increased for 500 fathoms.

Ocean-Observations by Staff-Commander E. K. Calver, 1869.

Casella's Hydrographic-Office pattern (*continued*).

N.B. The figures in antique type are rejected in forming the mean.

750 fathoms.		
Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	41·2°	
53	44·4	3·2
55	44·2	3·0
58	44·6	3·4
100–103 (Miller)	42·45	
41	46·2	3·75
42	46·2	3·75
43	46·2	3·75
100–103 (Miller)	42·0	
41	45·6	3·6
42	45·8	3·8
43	46·2	4·2
53	45·5	3·5
55	45·4	3·4
58	48·8	**6·8**
808 fathoms.		
100 (Miller)	41·4	
58	45·2	3·53 *
Mean........................		3·573
Correction for Miller ...		0·429
Error at 750 fathoms ...		4·002

1000 fathoms.		
Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	38·5°	
53	43·0	4·5
55	42·5	4·0
58	43·0	4·5
100–103 (Miller)	38·55	
41	43·8	5·25
42	43·5	4·95
43	47·0	**8·45**
100–103 (Miller)	38·8	
41	44·7	5·9
42	44·0	5·2
43	46·4	**7·6**
53	44·0	5·2
55	43·4	4·6
58	43·2	4·4
Mean........................		4·855
Correction for Miller ...		0·572
Error at 1000 fathoms...		5·427

* Reduced for 750 fathoms.

Ocean-Observations by Staff-Commander E. K. Calvert, 1869.

Casella's Hydrographic-Office pattern (*continued*).

N.B. The figures in antique type are rejected in forming the mean.

1250 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	37·9°	
41	44·2	6·3
42	43·5	5·6
43	43·5	5·6
100–103 (Miller)	37·3	
41	43·0	5·7
42	43·0	5·7
43	43·0	5·7
53	42·8	5·5
55	42·5	5·2
58	43·0	5·7
100–103 (Miller)	37·65	
41	42·8	5·15
42	43·0	5·35
43	43·0	5·35

Mean........................	5·571
Correction for Miller ...	0·715
Error at 1250 fathoms...	6·286

1500 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	36·9	
41	43·4	6·5
42	43·6	6·7
43	43·5	6·6
100–103 (Miller)	37·2	
41	43·0	5·8
42	43·0	5·8
43	43·0	5·8

Mean........................	6·200
Correction for Miller ...	0·858
Error at 1500 fathoms...	7·058

1750 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	36·7°	
41	43·0	6·3
42	43·0	6·3
43	43·8	**7·1**

Mean........................	6·300
Correction for Miller ...	1·001
Error at 1750 fathoms...	7·301

2090 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	36·3	
41	42·8	6·5
42	43·0	6·7
43	42·8	6·5

Mean........................	6·567
Correction for Miller ...	1·144
Error at 2000 fathoms...	7·711

Ocean-Observations by Staff-Commander E. K. Calver, 1869.

Pastorelli's Hydrographic-Office pattern.

N.B. The figures in antique type are rejected in forming the mean.

250 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	° 48·0	
71	49·2	1·2
74	51·2	**3·2**
100–103 (Miller)	48·5	
39	49·5	1·0
40	58·0	**9·5**
75	49·5	1·0
100–103 (Miller)	48·35	
38	51·2	**2·85**

Mean........................	1·067
Correction for Miller ...	0·143
Error for 250 fathoms...	1·210

500 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
101–103 (Miller)	46·75	
71	49·5	2·75
74	49·5	2·75
100–103 (Miller)	46·9	
39	49·5	2·6
40	58·0	**11·1**
75	47·5	**0·6**
100–103 (Miller)	47·5	
38	52·2	**4·7**

Mean........................	2·700
Correction for Miller ...	0·286
Error at 500 fathoms ...	2·986

750 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	° 41·2	
71	47·8	**6·6**
74	53·0	**11·8**
100–103 (Miller)	41·55	
39	46·2	4·65
40	50·4	**8·95**
75	45·6	4·05

Mean........................	4·350
Correction for Miller ...	0·429
Error at 750 fathoms ...	4·779

1000 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	38·5	
71	49·5	**11·0**
74	52·0	**13·5**
100–103 (Miller)	38·8	
39	45·5	6·7
40	...	...
75	43·8	5·0

Mean........................	5·850
Correction for Miller ...	0·572
Error at 1000 fathoms...	6·422

Ocean-Observations by Staff-Commander E. K. Calver, 1869.

Pastorelli's Hydrographic-Office pattern (*continued*).

N.B. The figures in antique type are rejected in forming the mean.

1250 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	37°·9	
39	44·5	6·6
40	50·0	**12·1**
75	44·0	6·1
100–103 (Miller)	37·9	
38	45·8	**7·9**
100–103 (Miller)	37·65	
39	44·0	6·35
40	50·3	**13·65**

Mean........................ 6·350
Correction for Miller ... 0·715
Error at 1250 fathoms... 7·065

1500 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	37·0	
39	44·5	7·5
40	44·6	7·6
75	43·5	6·5
100–103 (Miller)	36·9	
38	44·8	7·9
100–103 (Miller)	37·2	
39	44·0	6·8
40	64·6	**27·4**

Mean........................ 7·260
Correction for Miller ... 0·858
Error at 1500 fathoms... 8·118

1750 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	36°·7	
39	44·0	7·3
40	63·5	**26·8**

Mean........................ 7·300
Correction for Miller ... 1·001
Error at 1750 fathoms... 8·301

2090 fathoms.

Thermometer.	Minimum Index.	Difference from Miller.
100–103 (Miller)	36·3	
39	44·0	7·7
40	44·0	7·7

Mean........................ 7·700
Correction for Miller ... 1·144
Error at 2000 fathoms... 8·844

In the annexed diagram (Plate V.) the results obtained from the ocean-observations are laid down with those found by the use of the testing-apparatus; and it will be seen that there is considerable accordance between these determinations.

Progressive rate of Error of Hydrographic-Office pattern Thermometers as shown by the foregoing Tables of Ocean-Observations.

Casella.				Pastorelli.			
Depth.	Error.	First diff.	Second diff.	Depth.	Error.	First diff.	Second diff.
	°	°	°		°	°	°
0 ...	0·000			0 ...	0·000		
250 ...	1·329	1·329	+0·158	250 ...	1·210	1·210	+0·566
500 ...	2·816	1·487	−0·301	500 ...	2·986	1·776	+0·017
750 ...	4·002	1·186	+0·239	750 ...	4·779	1·793	−0·150
1000 ...	5·427	1·425	−0·566	1000 ...	6·422	1·643	−1·000
1250 ...	6·286	0·859	−0·087	1250 ...	7·065	0·643	+0·410
1500 ...	7·058	0·772	−0·529	1500 ...	8·118	1·053	−0·870
1750 ...	7·301	0·243	+0·167	1750 ...	8·301	0·183	+0·360
2000 ...	7·711	0·410		2000 ...	8·844	0·543	
			+0·564 −1·483 Difference = −0·919				+1·353 −2·020 Difference = −0·667
Equal to a decrease of effect at the rate of 0°·13 per 250 fathoms' pressure.				Equal to a decrease of effect at the rate of 0°·09 per 250 fathoms' pressure.			

Notwithstanding the unsatisfactory nature of the observations obtained by Pastorelli's thermometers by reason of the indices shifting, there is quite sufficient to prove that (contrary to the result of the experiments by hydraulic testing) the elasticity of the glass is not regular, or in ratio to the pressure, but that, after continuing regular up to a pressure of 1000 fathoms (1¼ ton), it decreases in a compound ratio to a pressure of 2000 fathoms (2½ tons), when its elasticity nearly ceases.

Comparison of the Errors of the Hydrographic-Office pattern Thermometers as found by the hydraulic testing-apparatus and by the Ocean-Observations.

Casella.					Pastorelli.				
Pressure.	Error.		Per 250 fathoms.		Pressure.	Error.		Per 250 fathoms.	
	Press.	Ocean.	Press.	Ocean.		Press.	Ocean.	Press.	Ocean.
fms.	°	°	°	°	fms.	°	°	°	°
250 ...	1·307	1·329	1·307	1·329	250 ...	1·482	1·210	1·482	1·210
500 ...	2·789	2·816	1·394	1·408	500 ...	2·664	2·986	1·332	1·493
750 ...	3·821	4·002	1·274	1·334	750 ...	4·279	4·779	1·426	1·593
1000 ...	4·853	5·427	1·213	1·357	1000 ...	5·195	6·422	1·299	1·606
1250 ...	5·860	6·286	1·172	1·257	1250 ...	6·743	7·065	1·349	1·413
1500 ...	7·392	7·058	1·232	1·176	1500 ...	7·625	8·118	1·271	1·353
1750 ...	8·199	7·301	1·171	1·043	1750 ...	9·307	8·303	1·329	1·186
2000 ...	9·638	7·711	1·205	0·964	2000 ...	10·106	8·844	1·263	1·105
2250 ...	10·838	……	1·204	……	2250 ...	11·438	……	1·271	……
2500 ...	12·270	……	1·227	……	2500 ...	12·520	……	1·252	……
Means ……………………			1·240	1·233	Means ……………………			1·327	1·370
Error at 2500 fathoms by the means………			12·4	12·3	Error at 2500 fathoms by the means ………			13·3	13·7

By this comparison, although the errors, as found by the two modes of observation, differ at individual depths or pressure, still the means of Casella's per 250 fathoms are almost the same, and those of Pastorelli's differ only three tenths of a degree in 2000 fathoms, the extent to which the comparison can be made.

It may be suggested that although the actual quantity of line to which the thermometers were attached in the ocean-observations was payed out, the certainty that the line was vertical throughout cannot be so fully depended on, especially at the greater depths; and if from the drift of the ship, by current or sea, the line beneath the surface assumed a curved line, the thermometers would not have attained the pressure of the depth indicated; at the same time, assuming (as is most natural) that the elasticity of the glass is not in exact proportion to the pressure, it would be advisable, in forming a scale for the correction of previous observations, to adopt a curve as nearly as possible between the results of the two modes of observation for each make of thermometer; and this curve is submitted in the accompanying diagram (Plate V.).

There can be little doubt that, without the aid of the Miller pattern, by an extended series of observations a scale could have been obtained to correct the Hydrographic-Office pattern to a very close approximation of the truth (in accordance with the proposed first intention of the experiments); but the timely suggestion of Dr. Miller has quite set at rest any difference of opinion as to the instrument for future use.

To correct the deep-sea temperatures obtained by Sir James Ross and others with a class of instruments that cannot be obtained for comparison, observations made by the Miller patterns at a few of the same positions, uninfluenced by known ocean-currents, at as nearly as possible the same time of year as they were obtained in, and at precisely the same depths, would enable a scale to be made for correction which would be applicable to the whole series, and be sufficiently accurate to utilize them.

Aware of the mechanical difficulties attending the construction of these instruments, where men of great experience in their manufacture have failed, it would perhaps seem superfluous to suggest an improvement; still it may be hoped that, with the fault before him, some ingenious mechanic may devise a means to rectify it: the unsatisfactory nature of the indicators is alluded to. From experience gained, there is reason to believe that the exceedingly fine hairs used as frictional springs do not retain all the elasticity they possess when first secured to the bar, but deteriorate by soaking continually in spirits; and it stands to reason that it should be so, as the spirit must deprive the hair of its natural oil*.

With the above defect in view, the only remedy that suggests itself is, that a thermometer should never be sent down singly, but pairs; and although the occasional divergence of their indications may raise a doubt, a little practice will enable the observer to detect the faulty indicator; but when they agree, greater confidence of correctness will be the consequence.

Deep-sea Metallic Thermometers.

Previously to the experiments and the adoption of the Miller-pattern Six's thermometer (which leaves little or nothing to be desired), the invention of a metallic thermometer that could be depended on for deep-sea purposes was a great desideratum; and although the necessity for one has passed away, a record of those that have been invented for the purpose may fitly be appended to this paper—the more especially as, after the lapse of years, it is often difficult to obtain the original type, or even to ascertain the principle on which they were constructed.

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* This has been partially remedied by Mr. Casella at the suggestion of the author, who, reasoning from the fact that the hair is a fine tube, proposed singeing or burning the end, and thus hermetically sealing it.

Johnson's Deep-sea Metallic Thermometer.

Invented by Mr. Henry Johnson, to be used simultaneously with his Deep-sea Pressure-gauge*, in the use of which temperature necessarily became an important element in calculating the depth, in determining how much of the variation in the volume of water indicated was due to variation of temperature.

Fig. 2.

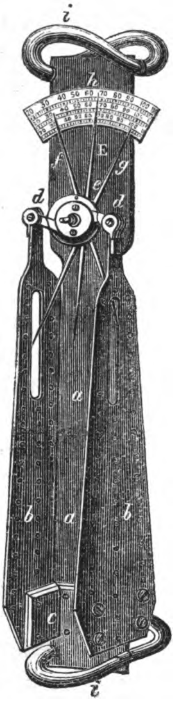

Fig. 1.

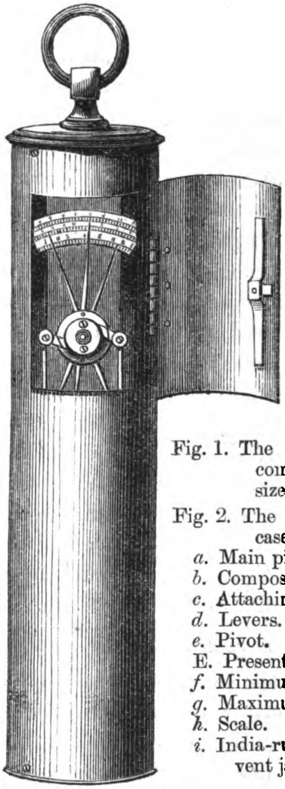

Fig. 1. The instrument in case complete: one-fourth size.

Fig. 2. The instrument out of case.

a. Main piece or standard.
b. Composite plates.
c. Attaching plates.
d. Levers.
e. Pivot.
E. Present-temp. indicator.
f. Minimum indicator.
g. Maximum indicator.
h. Scale.
i. India-rubber rings to prevent jar.

This instrument is composed of brass and steel, the well-known difference in the ratio of expansion and contraction by heat and cold of which is taken advantage of for ascertaining temperature. Compound bars of thin plates of these metals are riveted together, which slightly curve in one direction when heat has expanded the brass more than the steel, and attain a slight curve in the contrary direction when the cold has contracted the brass more than the steel. The indicator records the motions under change of temperature.

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* Mr. Johnson's pressure-gauge was tried in various forms; but (apart from temperature) owing, it is believed, to the difficulty of measuring the small difference, in quantity, of water compressed, and of getting that quantity free from air, it was pronounced impracticable for the purpose intended.

In the composition of the bars the proportion of brass (the more dilatable metal used) is double that of steel, or two thirds of brass to one of steel.

The maximum and minimum indicators are pieces of split brass, which, by its nip, causes enough friction to prevent their being moved by shaking or knocking, at the same time not enough to prevent the free action of the present-temperature indicator.

The pivot on which the indicator works is of gold, and the surrounding parts washed with the same metal, to prevent oxidation.

This instrument has often been condemned from its want of agreement with the mercurial thermometers sent down with it; but now that there is proof of the effect on the latter by pressure, that disagreement is accounted for, and in most cases in which its notification has been rejected it would now be found correct.

Saxton's Metallic Thermometer.

In the report of the Superintendent of the United-States Coast Survey of 1860, is contained an account of the deep-sea thermometric instruments used in the survey of the Gulf-Stream; and the instrument mainly depended on seems to have been an adaptation of the Breguet principle of the coil-form of two metals, by Joseph Saxton, Esq., and consists of two stout ribands of silver and platinum, carefully united with silver-solder and coiled spirally, the more expansive metal being within; a coil of gold, to which each metal is soldered, serves to prevent the tendency of the silver and platinum to separate: the lower part of the coil is affixed to a brass stem which passes up through the centre of the coil, while the upper end is fastened to the base of a short cylinder which keeps that end of the coil from turning, and consequently conveys the whole motion of the coil, caused by the unequal expansion or contraction of the two metals, to the lower end of the spindle, the turning of which is communicated to multiplying-wheels placed within the short cylinder, which serve to magnify the motion of the coil and move a hand, which in turn carries with it an index to record the extreme maximum or minimum.

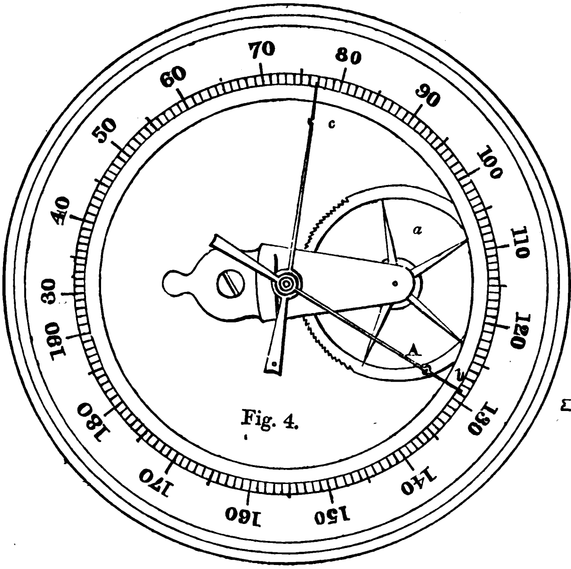


Fig. 4.

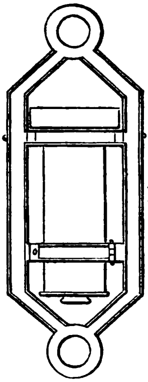


Fig. 1.

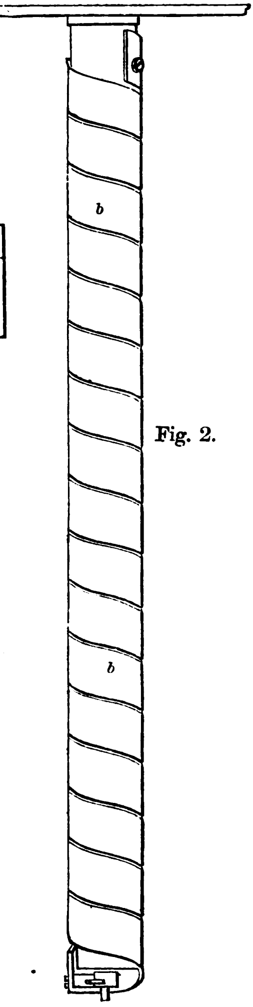


Fig. 2.

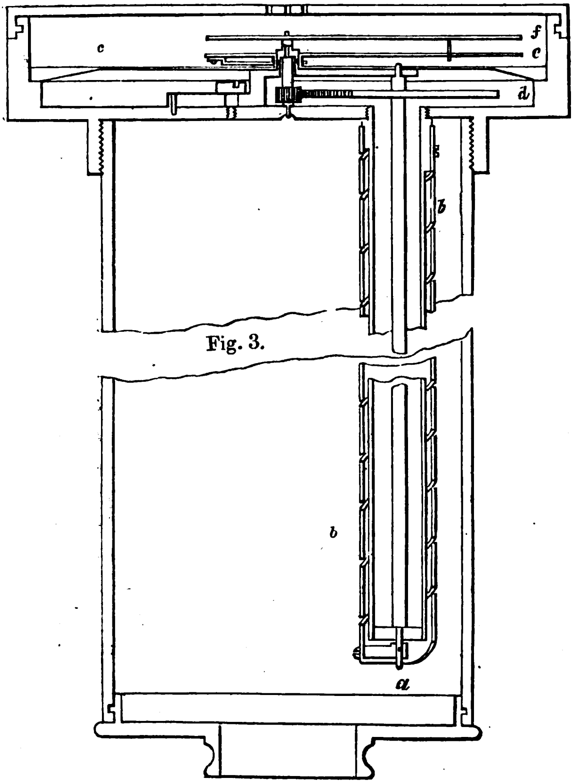


Fig. 3.

This instrument was found to have a considerable error under pressure, and it is supposed that the solder by which the two metals are cemented together was so affected by the compression as to cause the error; but it may be due to the construction of the instrument itself, as there can be no certainty that the expansion and contraction of the two metals *are* communicated at the end of the spiral ribands, and may not be developed at the sides (the ribands not being close to the bar around which it is coiled.

If the communication of the contraction and expansion could be depended on at the end of the ribands, it would seem that a simple but long coil of wire could be so encased that the direct action could be communicated to an indicator for the purpose of registering the temperature indicated by its elongation or expansion and contraction.

DESCRIPTION OF WOODCUT.

Fig. 1. The instrument complete: one-sixth size.

Fig. 2. The stem and coil: full size.
a. Stem. *b.* Silver and platinum coil.

Fig. 3. Section: full size.
a. The stem. *b.* The coil. *c.* Short cylinder.
d. Magnifying wheel. *e.* Present-temperature indicator.
f. Registering indicator.

Fig. 4. Short cylinder: full size.
a. Magnifying wheel. *b.* Present-temperature indicator.
c. Registering indicator.

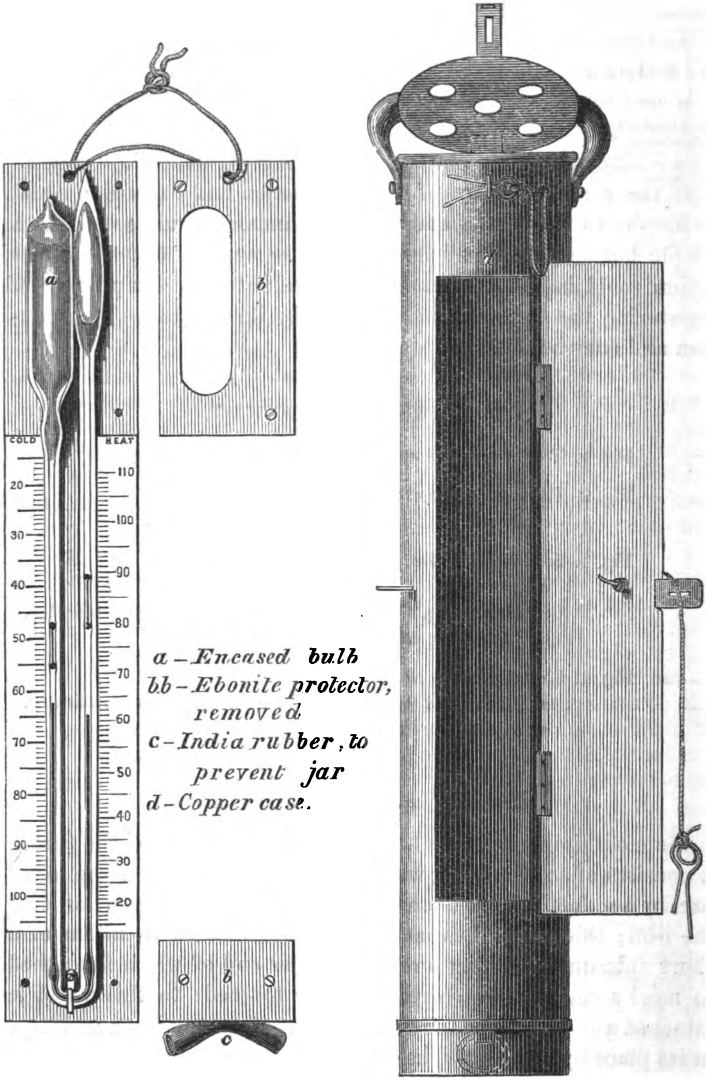
Hearder's Metallic Thermometer

is the most simple and has the most direct action of the three: it consists of an iron tube, within which, and secured to the lower part by a socket, is a bar of another metal of unequal expansion with the iron; this unequal expansion is communicated by means of a short fulcrum to a long lever, the upper end of which is toothed to meet a small wheel correspondingly toothed: to this wheel is attached the hand, the index being moved by the hand and kept in its place by means of friction.

An instrument of this description has not been completed as a thermometer; but the author has seen the action of an experimental instrument, and it seemed to answer well.

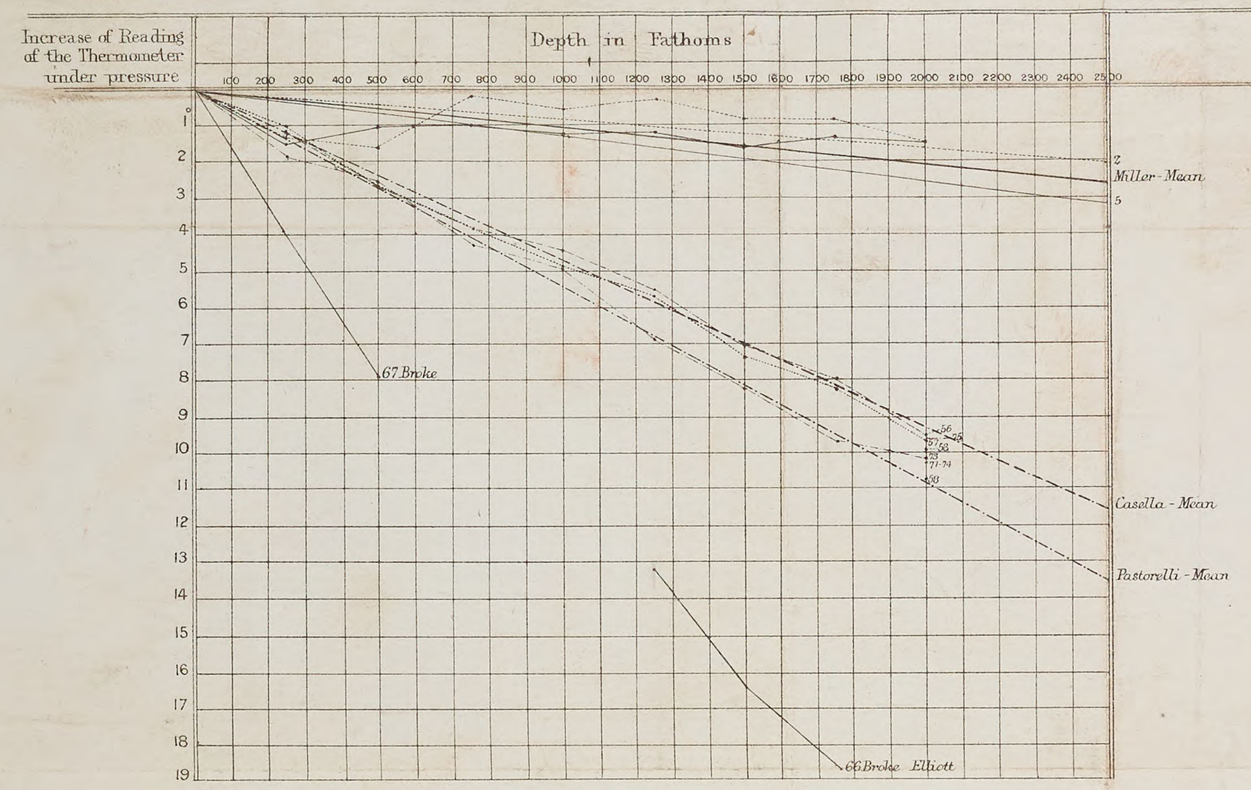
It is the invention of Dr. Jonathan Hearder, of Plymouth.

Six's Self-registering Deep-sea Thermometer (Miller pattern).

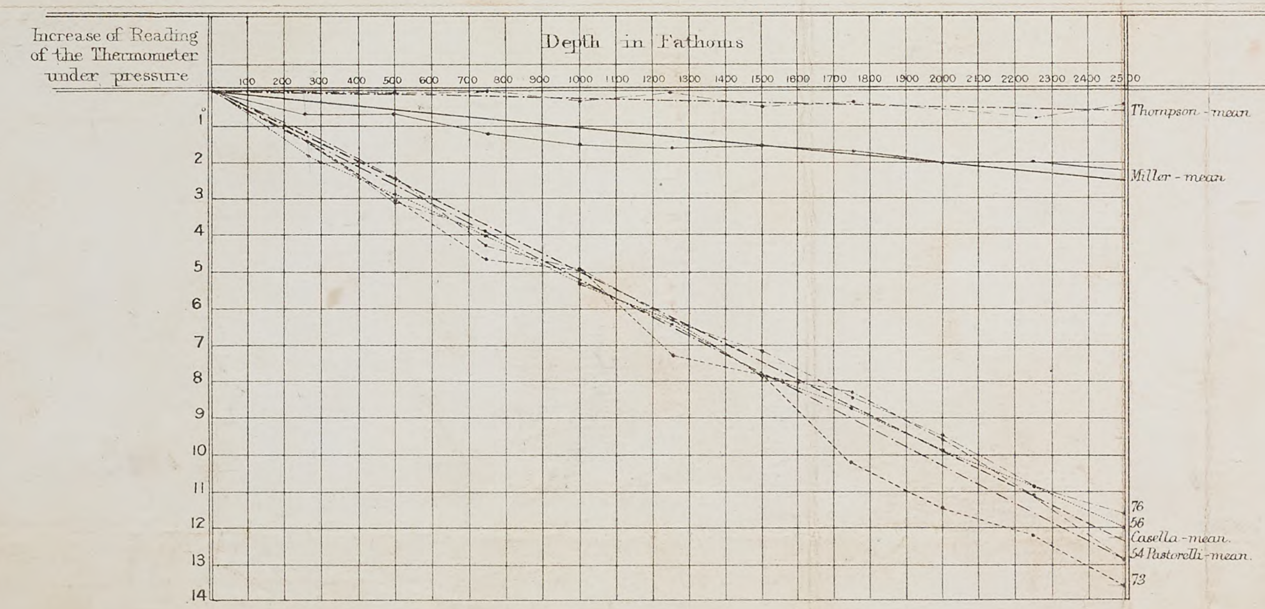


a – Encased bulb
bb – Ebonite protector, removed
c – India rubber, to prevent jar
d – Copper case.

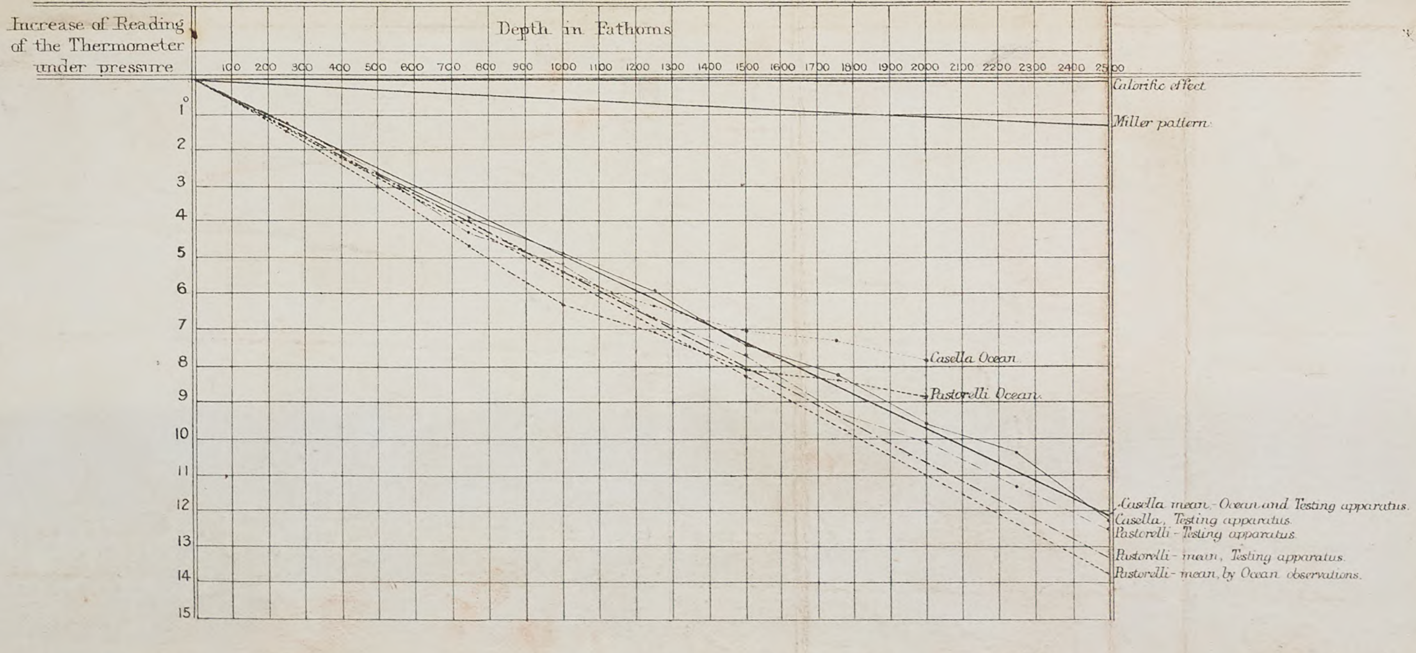
N° 1. FIRST SERIES OF EXPERIMENTS.



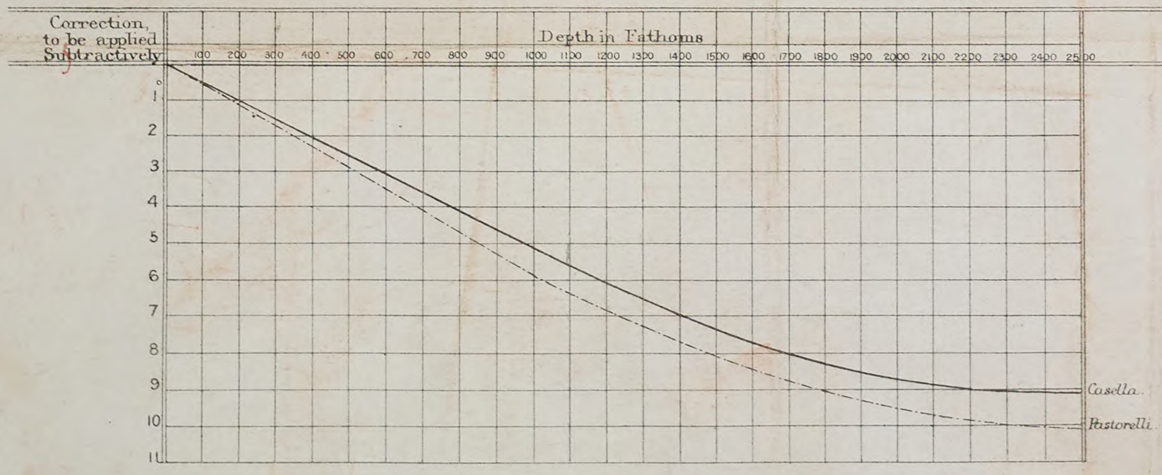
N° 2. SECOND SERIES OF EXPERIMENTS.



N° 3. DIAGRAM SHOWING THE CALORIFIC EFFECT PRODUCED BY THE COMPRESSION IN THE CYLINDER OF THE TESTING APPARATUS, THE ERROR OF THE MILLER PATTERN AND THE ERRORS OF THE HYDRO-GRAPHIC OFFICE PATTERN AS FOUND BY TESTING APPARATUS AND OCEAN OBSERVATIONS.



N° 4. DIAGRAM FOR CORRECTING HYDROGRAPHIC OFFICE PATTERN THERMOMETER.



Mintern Bros. lith.